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Is Increased Dietary Protein Necessary or Beneficial for Individuals with a Physically Active Lifestyle?

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Introduction

Although in the 1800s it was believed that protein was the major fuel for exercise (von Liebig 1842), information obtained during the early part of the 20th century made it clear that carbohydrate (CHO) and fat actually provide most of the fuel for exercise (Åstrand and Rodahl 1986). So complete was this reversal in scientific thinking that despite the phenomenal expansion of knowledge regarding exercise metabolism during the past 25 years, there has been relatively little study of the role that is played by protein (Lemon 1987, 1991a). As a result, the current recommended dietary allowance (RDA) for protein (NRC 1989) does not include an additional allowance for those who regularly engage in physical exercise.

Perhaps unaware of this scientific literature or influenced by myth and/or their own trial and error experimentation, during this same time period athletes have generally consumed diets high in protein (Grandjean 1988). As a graduate student looking for research ideas, I was piqued by this contradiction between the scientific and athletic communities. Further fueled by a few fascinating observations in the scientific literature during the 1970s (Felig and Wahren 1971, Haralambie and Berg 1976) as well as by the support of my major professors, we completed a series of experiments designed to assess the role of protein as a fuel source during exercise (Lemon and Mullin 1980, Lemon and Nagle 1981, Lemon et al. 1982). Our results as well as those of several other studies published about the same time (Dohm et al. 1977, White and Brooks 1981) convinced us that this issue was in fact extremely complex. Since then, a number of studies utilizing a variety of measurement techniques have produced some interesting data that suggest regular physical exercise has dramatic effects on protein metabolism (Lemon 1992). This paper provides a brief summary of some of these data and discusses their implications for those with a physically active lifestyle.

Overview of Protein Metabolism

Central to an understanding of the literature regarding the effects of a physically active lifestyle on dietary protein

needs is a clear understanding of how protein is metabolized (**Figure 1**). The component parts of protein (amino acids) can enter into the body's free amino acid pool (which encompasses both body fluids and tissues) during digestion from the protein foods we ingest, from the breakdown of body protein, and/or as dispensable (nonessential) amino acids synthesized from a carbon source (CHO or fat) and NH_4 . Normally, these processes are in equilibrium such that the breakdown of body protein is replaced by protein synthesis that uses amino acids available from the free pool. When protein intake is inadequate, there are insufficient amino acids entering the free pool to replace those lost from protein degradation. Over time this leads to losses in both muscle size and strength and, as a result, decreased physical performance. If this situation continues, health can be adversely affected. In contrast, when protein intake is excessive, the surplus amino acid carbon is oxidized and/or converted to CHO or fat and stored, and the surplus nitrogen is largely excreted (primarily as urea in the urine).

However, physical activity has profound effects on protein metabolism (Lemon 1992). For example, if a muscle works intermittently against a significant overload (typically referred to as heavy resistance or strength exercise), the result after a period of training is an anabolic

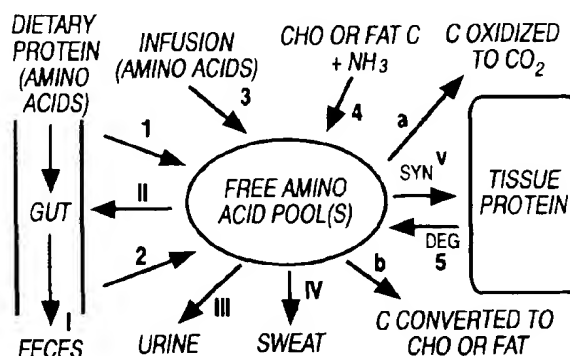


Figure 1. Simplified overview of protein metabolism. Arabic numbers denote ways that amino acids can enter the body's free pool (through which all amino acids pass). Roman numerals denote ways that amino acid nitrogen can leave the free pool. Letters denote ways that amino acid carbon can leave the free pool.

(muscle building) effect. This occurs because the stimulation of myofibrillar protein synthesis exceeds any increase in protein degradation (Chesley et al. 1992). Despite the intense nature of this type of physical activity amino acids appear to contribute insignificantly to fuel supply, at least with heavy resistance exercise (Tarnopolsky et al. 1991). If a muscle works rhythmically against a more moderate load over a more prolonged time period (typically referred to as endurance exercise), the result after a period of training is an increase in mitochondrial (enzymatic), not myofibrillar, protein synthesis (Holloszy and Coyle 1984). Moreover, during this type of exercise, the total quantity of amino acids oxidized can be significant (Evans et al. 1983).

Protein metabolism has been traditionally assessed by measurements of nitrogen balance (difference between nitrogen intake and excretion) (NRC 1989). When intake exceeds excretion, protein is being retained by the body. This situation is necessary for growth and is generally referred to as positive nitrogen balance. (Although positive nitrogen status is more correct, the term nitrogen balance is so established in the literature it is unlikely to change.) Conversely, the situation where excretion exceeds intake is known as negative nitrogen balance and means that body protein is being degraded at a greater rate than it is being synthesized. This nitrogen balance procedure is classic, but it is far from ideal because it is very labor intensive and somewhat limited because it cannot detect changes in the various component processes of protein metabolism.

More recently, protein metabolism has also been assessed by use of metabolic tracers (i.e., radioactive or stable isotopes, such as ^{14}C , ^{13}C , ^{15}N , etc.). With this technique it is possible to investigate the component processes involved in protein metabolism (Young et al. 1989, Wolfe 1992). However, tracer methodology also has several drawbacks, including expense, degree of invasiveness, and whether the various assumptions on which it depends are valid (Garlick et al. 1994, Rennie et al. 1994b).

Effects of Physical Activity on Protein Requirements

Heavy Resistance Exercise

It is well known that regular heavy resistance exercise stimulates muscle growth (Goldberg et al. 1975). Assuming that available raw materials (amino acids) are limiting, increased dietary protein could theoretically potentiate the enhanced protein synthesis that results from this type of training (Lemon 1991b). Whether this actually occurs is not a trivial question because, in addition to its obvious importance to athletes, it has application to several populations in whom muscle atrophy is a concern (e.g., inactivity, aging, muscle disease/injury, space flight, etc.). Based on the very high protein intakes of many sportsmen/women, it appears that the athletic population is convinced of this effect. Although the ability of some athletes to build muscle mass is certainly impressive, the fact re-

mains that the evidence on which this opinion is based is far from objective. Clearly, this information alone is insufficient to make a definitive conclusion about whether increased dietary protein is necessary to maximize muscle development.

Although considerable debate has gone on for years (Cathcart 1925, Lemon 1987, Butterfield 1991, Hickson and Wolinsky 1994, Layman et al. 1994, Poortmans 1994, Rennie et al. 1994a), recent scientific data indicate that dietary protein intake in excess of the current RDA is likely needed for optimal muscle growth. However, the benefit appears to plateau at intakes well below the intakes typically consumed by many athletes. For example, it has been shown that greater gains in body mass occur over 4 weeks of heavy resistance training when young men consumed 3.3 versus 1.3 g protein/kg body mass/d (Fern et al. 1991). In agreement with these data, Meredith et al. (1992) reported that a daily dietary supplement containing 23 g protein combined with heavy resistance training can enhance muscle mass gains relative to similar subjects who trained without the supplement. These studies provide objective support that increased dietary protein combined with regular heavy resistance exercise can enhance muscle development relative to training alone.

At least two additional studies have observed negative nitrogen balance in young men engaged in heavy resistance training while consuming dietary protein at the RDA (Lemon et al. 1992, Tarnopolsky et al. 1992). These data indicate that the RDA (which was determined using subjects who were essentially sedentary) is insufficient for individuals who are involved in a heavy resistance training program. By use of linear regression methodology (dietary protein versus nitrogen balance, Figure 2), these studies concluded that the recommended intake for individuals involved in heavy resistance training should be 1.7 and 1.8 g protein/kg/d, respectively.

In the Fern et al. (1991) study discussed above, changes in protein metabolism were also assessed with the meta-

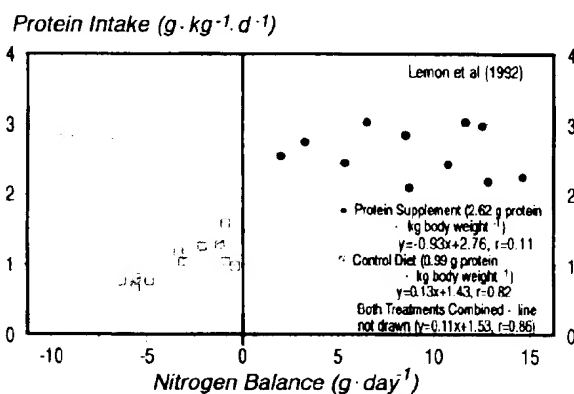


Figure 2. Dietary protein intake versus nitrogen balance in individuals engaged in a heavy resistance (strength) training program with a protein intake of 0.99 versus 2.62 g · kg⁻¹ · d⁻¹ (from Lemon et al. 1992)

holic tracer technique when the subjects consumed different quantities of protein (3.3 versus 1.3 g/kg/d). Consistent with the observed greater gains in body mass, there was a greater increase in protein synthesis with the higher protein intake; however, the observed 150% increase in amino acid oxidation clearly indicates that the optimal protein intake had been exceeded. Tarnopolsky et al. (1992) studied protein intake with heavy resistance exercise by use of the tracer technique and found that protein synthesis was increased when dietary protein increased to 1.4 from 0.9 g/kg/d but was not further elevated when protein intake was 2.4 g/kg/d (Figure 3). These data support the results of Fern et al. (1991) that individuals who engage in heavy resistance exercise will benefit from protein intakes in excess of the RDA. In addition, they further indicate that even an intake of 2.4 g/kg/d is excessive, because at this intake, amino acid oxidation increased without any increase in protein synthesis.

Together, these studies provide strong evidence that a protein intake of about 1.7–1.8 g/kg/d, when combined with heavy resistance exercise, will enhance muscle development compared with similar training with an intake of 0.8 g/kg/d. However, it is important to note that there is little good evidence that the very high protein intakes (>2 g/kg/d) typically consumed by strength athletes are beneficial. Moreover, it is possible to obtain this quantity of protein without special supplementation assuming a mixed diet containing sufficient energy is consumed (e.g., a 21,000 kJ [5000 kcal]) diet containing 10% protein would provide about 126 g protein or 1.8 g/kg/d for a 70-kg individual).

Unfortunately, scientific knowledge in the area of dietary protein needs with exercise is extremely limited at present because most of the data have been collected in young male subjects (18–25 years). Furthermore, although claims of strength gains with high protein intakes are common, few performance studies have actually documented this benefit. Future studies need to focus on women, other age groups, and specific groups that may have elevated dietary protein requirements as a result of other existing conditions, such as those who are experiencing periods of rapid growth (children, adolescents, women who are pregnant) and/or those who are less likely to consume an optimal mixture of nutrients (dieters, vegetarians, elderly individuals, etc.).

Endurance Exercise

Clearly, endurance exercise does not develop muscle mass to the extent that heavy resistance exercise does, and therefore availability of raw materials for the synthesis of myofibrillar protein is less likely to be limiting for individuals who regularly engage in this form of exercise. However, this does not necessarily mean that the RDA is adequate for endurance exercisers, because this type of exercise also alters protein metabolism albeit in a different manner than with heavy resistance exercise (i.e., in-

Whole Body Protein Synthesis ($\text{mg} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$)

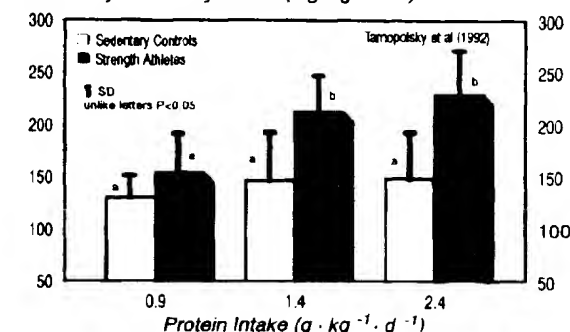


Figure 3. Effect of supplemental dietary protein on protein synthesis in individuals participating in a heavy resistance (strength) training program versus sedentary controls (Tarnopolsky et al. 1992).

creases exercise amino acid oxidation) (Rennie et al. 1980, White and Brooks 1981, Lemon et al. 1982, 1985, Babij et al. 1983) and with time leads to an increase in mitochondrial protein content (Holloszy and Coyle 1984, Faulkner et al. 1994). As a result, dietary protein in excess of the RDA may be necessary to cover any increased amino acid needs due to this increased oxidation and/or to maximize these training adaptations.

Although only a few individual amino acids (primarily the branched chain amino acids) have been extensively studied, the magnitude of the amino acid oxidation appears to be proportional to both exercise intensity (Babij et al. 1983, Figure 4) and exercise duration (Haralambie and Berg 1976, Figure 5). The former effect appears to be the result of an exercise intensity-dependent activation of the limiting enzyme (branched chain ketoacid dehydrogenase) in the branched chain amino acid oxidation pathway (Kasperek and Snider 1987, Wagenmakers et al. 1991). The latter effect is probably the result of reduced CHO availability as exercise is prolonged (Lemon and Mullin 1980, Figure 6).

Whole Body Leucine Flux Oxidized (%)

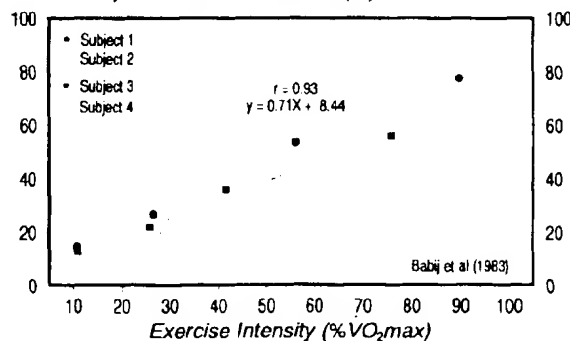


Figure 4. Effect of endurance exercise intensity on oxidation of the branched-chain amino acid leucine (from Babij et al. 1983).

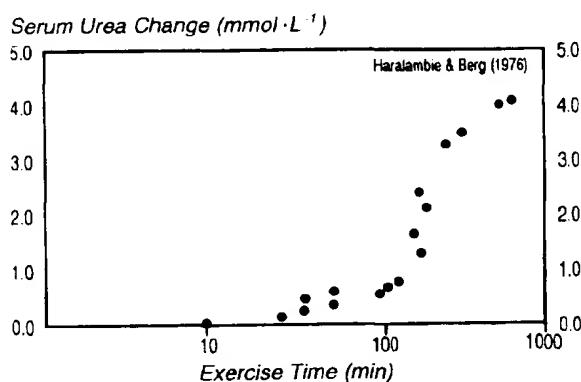


Figure 5. Effect of duration of moderate intensity endurance exercise on the accumulation of urea (major end product of protein metabolism) in the serum (from Haralambie and Berg 1976).

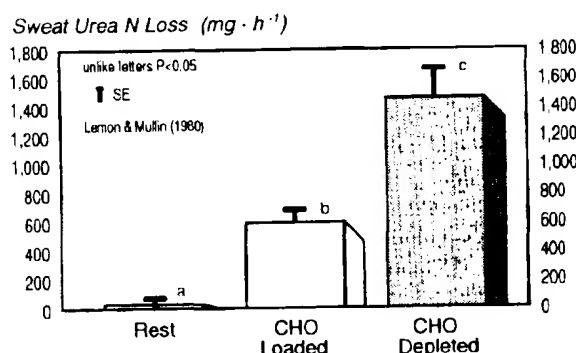


Figure 6. Effect of reduced CHO availability on excretion of urea (major end product of protein metabolism) with exercise (60 minutes of cycle exercise at 61% $\dot{V}O_{2\max}$) sweat (from Lemon and Berg 1980).

The increased amino acid oxidation can be substantial (as much as 86% of the daily requirement of one particular amino acid [leucine] with as little as 2 hours of moderate intensity exercise [55% $\dot{V}O_{2\max}$]) and therefore could result in altered requirements (Evans et al. 1983). Although additional study is necessary before it is possible to extend these data to all amino acids, it appears that the oxidation of several others must also increase, because a variety of studies have reported increases in urea (major end product of amino acid oxidation) excretion as a result of moderate to high intensity endurance exercise (Dohm et al. 1987, Lemon 1994). Moreover, some (Dohm et al. 1977, Henderson et al. 1985) but not all (Hood and Terjung 1987) data indicate that endurance training adaptations can further increase exercise amino acid oxidation (Figure 7). If so, this could explain the conclusions from several different laboratories that used both nitrogen balance and metabolic tracer methodology (Gontzea 1974, Tarnopolsky et al. 1988, Brouns et al. 1989, Friedman and Lemon 1989, Meredith et al. 1989) that endurance trained individuals should consume about 1.2–1.4 g protein/kg/d (150–175% of the current RDA).

Although not directly quantifiable in terms of dietary protein needs, there are several other pieces of evidence that endurance exercise may increase one's protein requirement. For example, endurance exercise increases muscle ammonia (an end product of amino acid metabolism) and muscle total and essential amino acids (ones that cannot be produced in the body) without increasing muscle branched chain amino acids (MacLean et al. 1991). In addition, urinary excretion of 3-methylhistidine (an amino acid that is excreted in the urine following myofibrillar protein degradation) (Dohm et al. 1987) and urea excretion (Refsum and Stromme 1974, Dohm et al. 1982, Dolny and Lemon 1988, Tarnopolsky et al. 1990) increase with endurance exercise. Finally, as with heavy resistance exercise, most of the studies completed to date have used young male subjects, and few have made performance measures. As a result, the effect (if any) of small insufficiencies in protein intake on athletic success remains unclear. Future investigations should focus on other populations, especially those that are potentially high risk. Interestingly, there is some information suggesting that, relative to males, females may utilize less protein with endurance exercise (Tapscott et al. 1982, Tarnopolsky et al. 1990, Phillips et al. 1993), and although active elderly subjects have not been systematically studied, recent data suggest that protein requirements are higher in the elderly (Campbell et al. 1994); therefore, the needs of the physically active elderly may be even greater.

Negative Health Concerns of High Dietary Protein/Amino Acids

It is frequently stated that high protein intakes should be avoided because they can be hazardous; however, the potential adverse effects appear to have been exaggerated. For example, potential kidney problems have been extrapolated from studies on individuals with impaired kidney function (Brenner et al. 1982). Although large protein intakes place an additional workload on the kidney (due to

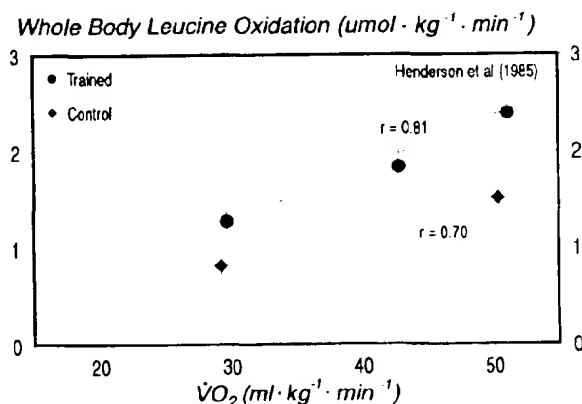


Figure 7. Effect of endurance exercise training on oxidation of one of the branched-chain amino acids (leucine) (from Henderson et al. 1985).

the increased nitrogen load), if this caused serious problems in healthy individuals, there should be a significant incidence of kidney problems in strength/power athletes. There is, however, no such evidence in the scientific literature. Further, studies on animals with very high protein intakes for more than half their lifespan have not revealed any serious adverse effects (Zaragoza et al. 1987).

Of some concern is the increased water loss (dehydration) associated with excretion of the additional nitrogen with high protein diets, especially in a physically active population that already has large water losses due to their high rates of sweating. This means that fluid replacement must be monitored closely when protein intake is high.

Some data suggest that high protein diets lead to increased urinary calcium loss (Allen et al. 1979), which could be hazardous at least for females due to its involvement with bone health. Fortunately, this adverse effect is only a problem with high intakes of purified protein, because the high phosphate content of food protein negates this effect (Flynn 1985).

High protein diets are often considered to be atherogenic because of the associated fat intake (Carroll 1982). However, these concerns may also have been overstated because the strong association between animal protein and plasma cholesterol observed in animal studies does not appear to apply to humans (West 1985).

Perhaps the area of greatest concern is the intake of large quantities of individual amino acids. This is often overlooked because it has only been possible in recent years with the commercial development of individual amino acid supplements. Although largely untested, many claims have been made regarding the possible ability of a variety of individual amino acids to enhance exercise performance. At least in theory, several of these could be beneficial (Brodan et al. 1974, Isidori et al. 1978, Kasai et al. 1978, Maughan and Sadler 1983, Segura and Venura 1988, Wesson et al. 1988, Bucci et al. 1990, Blomstrand et al. 1991, Krieder et al. 1992, Fogelholm et al. 1993, Lambert et al. 1993, Newsholme and Parry-Billings 1994). However, considerable potential also exists for serious complications, including absorption problems, metabolic imbalances, altered neurotransmitter activity, and even toxicity (Harper et al. 1970, Benevenga and Steele 1984, Yokogoshi et al. 1987, Tenman and Hainline 1991). Considerable caution is recommended relative to the use of any of these supplements until more information becomes available.

Summary and Conclusions

For most of the 20th century, scientists have believed that protein needs are not altered by physical exercise. In contrast, athletes are typically convinced that additional dietary protein can significantly enhance exercise performance. Until recently, the opinion of the athletes has been largely unsubstantiated in the scientific literature. However, since the 1970s, an increasing number of studies have appeared that indicate

dietary protein needs are elevated in individuals who are regularly physically active. Together, these data suggest that the RDA for those who engage in regular endurance exercise should be about 1.2–1.4 g protein/kg body mass/d (150–175% of the current RDA) and 1.7–1.8 g protein/kg body mass/d (212–225% of the current RDA) for strength exercisers. Fortunately, the typical North American diet contains protein near these quantities, so most individuals who decide to begin an exercise program will obtain sufficient protein as long as their diet is mixed and they are careful to consume adequate energy. Populations at greatest risk for consuming insufficient protein include any group that restricts energy intake (those on diets) or high quality protein sources (vegetarians) as well as any group that has a requirement higher than normal due to another existing condition (growing individuals). Future studies should focus on these groups. Moreover, few exercise performance measures have been made, so any negative effect of insufficient dietary protein on athletic success needs to be determined. Supplementation of several individual amino acids may be beneficial for physically active individuals, but considerable potential risk is also present. Intake of large quantities of individual amino acids is not recommended until much more information is available.

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